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Evaluation of Growth Curves of Brahman Cattle of Various Frame Sizes[1,2,3]

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ABSTRACT: Partial stage and complete life-cycle growth curves of Brahman cattle were obtained for small, medium, and large frame sizes for a herd under grazing conditions in a subtropical environment. Data were grouped into three stages: birth to weaning (stage 1), weaning to 20 mo (males) or 32 mo (females) of age (stage 2), and 32 mo of age to maturity (females only; stage 3). Within each stage, multiplicative growth models were developed for each frame size and sex. Body weight growth on age t was represented as $\exp(a + bt + ct^2)$ for stages 1 and 2, and as $\exp(A + B\exp(kt))$ for stage 3. The effects of sire and progeny within sire were considered in all models. For stages 2 and 3, the effect of season was also included. To obtain complete life-cycle curves, a growth stage-multiplicative model with stages 1 and 2 was defined; stage 3 was also included for females. Due to a 1-mo adaptation period after weaning, a transition stage between stages 1 and 2 was defined and represented by the model $\exp(a + bt)$. In stage 1, the shape of the growth curve differed ($P < .05$) among frame size groups; sex did not affect the shape of the growth curves, but bull calves had heavier ($P < .05$) weights than heifer calves. In stage 2, the shape of the growth curves did not differ among frame sizes, but BW differed among frame sizes ($P < .05$) and sex affected ($P < .05$) the shape of the growth curves. In stage 3, the shape of the growth curves differed ($P < .05$) among frame sizes. There were sire effects ($P < .05$) for stages 1 and 2, but sire effects were not significant for stage 3. Season effects were important ($P < .05$) for stages 1 and 2. These results suggest that variability in growth patterns provides an opportunity to use management and nutrition to improve production efficiency in cattle of different frame sizes.

Key Words: Beef Cattle, Body Weight, Brahman, Growth Curve, Growth Models, Growth Stages

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Introduction

Growth models summarize information needed to understand the biological phenomenon of growth, which is an important component in beef production systems. Development of a growth model that describes the growth pattern of a herd within a particular environment and management system may be useful to determine the relative importance of factors affecting production efficiency. A research project was initiated in 1984 to investigate the relationship between frame size and reproductive efficiency in Brahman cattle in a subtropical environment in Florida (Olson et al., 1989; Olson, 1993). The primary objective of the present study was to characterize growth curves for these small, medium, and large frame Brahman cattle. Previous studies of growth curves in cattle (Brown et al., 1976; DeNise and Brinks, 1985; Johnson et al., 1990; Beltran et al., 1992) focused on general patterns of life-cycle growth. Our approach was directed at analyzing growth performance of the herds during each of three biological stages (birth to weaning, weaning to 20 mo [males] or 32 mo [females] of age, and 32 mo of age [females] to maturity). Additional objectives were to determine the effects of sex and frame size on the pattern of the growth curve and to evaluate related effects of season.

[1]Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

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Materials and Methods

At the Subtropical Agricultural Research Station, Brooksville, Florida, the Brahman cow herd was divided into small, medium, and large frame groups based on hip heights beginning in 1984, and cows were bred to sires of comparable heights. Hip height characterization for the frame groups is presented in Table 1. To study growth curves for each frame size, we used a set of progeny BW collected from 1985 to 1993. Due to the influence of variation in management and nutrition on the pattern of the growth curve, data were grouped into three stages: birth to weaning (stage 1), weaning through 20 mo (males) or 32 mo (females) of age (stage 2), and 32 mo of age to maturity (females only; stage 3). All animals were weaned in September, grouped by sex, and fed a commercially prepared medicated supplement (65% TDN, 14% CP, plus antibiotics) for approximately 1 mo. Heifers were fed .91 to 2.27 kg/d of concentrate depending on the year, and hay (bahiagrass, perennial peanut, or alyce clover) was provided free choice during winter until spring of the following year when growth of bahiagrass pasture was adequate to support the heifers. Bulls were fed 4.54 kg/d of concentrate, and bahiagrass hay was offered free choice during periods of low forage availability for about 1 yr after weaning. As heifers approached 2 yr of age during their second winter, they were fed bahiagrass hay free choice and 1.81 kg/d of molasses. During winter, mature cows and first-calf heifers were fed bahiagrass hay free choice plus .91 kg/d of 20% CP range cubes or 2.27 to 3.18 kg/d of perennial peanut hay from first frost (November) through spring of the following year. Beginning at calving, cows were fed an additional 1.81 kg/d of molasses. Minerals were provided free choice to all cattle year round.

Multiplicative Growth Models. A multiplicative model (Menchaca, 1991) was used to represent BW growth within each growth stage. Due to the characteristics of the experimental data, factors such as frame, sex, sire, animal, and season were hypothesized to affect pattern of the growth curves. Sire (confounded with year) and animal were used in models to extract identifiable sources of variation; analysis of these effects were not an objective of this study. For stage 3, a complementary Brody's asymptotic growth curve representation was used. The multiplicative growth model has the following characteristics: it is a repeated measures design; growth is represented as a polynomial in the logarithmic scale; effects are considered multiplicative (i.e., proportional to the magnitude of body weight); the model includes longitudinal effects (i.e., effects over the entire curve [animal, sire, etc.]) and perpendicular effects (i.e., effects that change the pattern of the curve in a period of time within the curve [month, season, etc.]); and the experimental error is considered multiplicative (i.e., proportional to the magnitude of body weight). In addition, the instantaneous BW gain curve (the derivative of the BW growth curve) was used as a complement for the study of the growth process. Multiplicative growth models have the general form (Menchaca, 1991)

$$W_{ijk} = A \exp(bt + ct^2 + dt^3) \; L_i \; P_j \; E_{ijk},$$

where W_{ijk} are body weights, A is a constant for every observation, b, c, and d are growth curve parameters on age t where the order of the polynomial expression depends on the growth stage application, L_i is the i^{th} longitudinal effect, P_j is the j^{th} perpendicular effect, and E_{ijk} are random errors.

The following side conditions on the parameters for longitudinal and perpendicular effects (L_i, i = 1, 2, ..., I, and P_j, j = 1, 2, ..., J) and their estimates (^) are imposed:

$$\Pi_i \; \hat{L}_i = \Pi_j \; \hat{P}_j = 1$$

The side conditions cause the multiplicative parameters to be handled in the sense of proportions, or percentages if they are multiplied by 100. Tests and confidence intervals within the repeated dimension are affected due to the existence of autocorrelation and heterogeneity of variances of the errors in this repeated measures pattern. Nevertheless, the logarithmic transformation leads to stabilized variances (Vieira and Hoffmann, 1977), which reduces the difference between actual and nominal probability of type I error, as can be seen in the tables developed by Collier et al. (1967).

Statistical Analysis. Statistical analysis was performed in the logarithmic scale with GLM and MIXED procedures of SAS (1985, 1992). To test differences in shape of curves for frame and sex, the Extra Sum of Squares Principle (Draper and Smith, 1968) was used (i.e., the difference of variation between the model that contains a set of regression coefficients for each variant and the model that contains a common set of coefficients of regression).

Stage 1: Birth to Weaning. In this stage, calves were reared with their dams on pasture. Body weights were collected from 1985 to 1993 (Table 2). For years 1985 to 1988 there were three observations per animal:

Table 1. Mean hip heights (cm) of small, medium, and large frame Brahman cattle at weaning, 2 yr of age, and 5 yr of age and older[a]

	Age		
Frame	Weaning	2 yr	≥5 yr
Small	111.0	130.3	133.6
Medium	114.0	136.4	137.9
Large	118.1	140.2	141.0

[a]From Olson et al. (1989) and Olson (1993).

Table 2. Number of sires, animals, and total number of observations by frame size and sex for each of three stages of growth

Set	Stage 1[a]			Stage 2[b]			Stage 3[c]		
	Sires	Animals	Observations	Sires	Animals	Observations	Sires	Animals	Observations
Small frame									
Male	12	138	331	10	84	641	—	—	—
Female	12	140	334	10	109	1,426	7	61	934
Medium frame									
Male	4	61	158	4	33	202	—	—	—
Female	4	46	118	4	43	464	3	24	339
Large frame									
Male	12	150	369	10	88	623	—	—	—
Female	12	135	339	10	112	1,346	6	69	1,043
Total	28	670	1,649	24	469	4,702	16	154	2,316

[a]Birth to weaning.
[b]Weaning to 20 mo of age (males) or 32 mo of age (females).
[c]32 mo of age to maturity.

birth, weaning (mean of 204 d), and an intermediate weight (3 mo before weaning). For years 1989 to 1993 there were two observations per animal: birth and weaning.

Multiplicative growth models were fitted for each frame by sex group with sire and progeny within sire effects included in the model. Initially, the simple linear regression of the logarithm of BW on age t was used to represent the growth curve from birth to weaning, as was stated by Brody (1945). The scatter diagram from the analysis of residuals showed a pattern that suggested the need for an additional term in the model, i.e., the quadratic term. Thus, a quadratic term was included in the model, which was highly significant, and the residuals followed the desired pattern. This quadratic expression showed the existence of a point of inflection within the interval from birth to weaning (i.e., a point where a maximum was achieved for the instantaneous BW gain curve). To validate this result, a data set between birth and weaning was used (seven Romosinuano calves from Brahman recipient cows with six age points per calf from birth to weaning; Chase et al., 1994). There was a point of inflection at 78, 88, or 95 d, depending on the fitted model being Gompertz, Logistic, or our model, respectively. This result supported the initial finding of a point of inflection between birth and weaning for the cattle within this environment and management system. Finally, a quadratic regression was used to represent the logarithm of BW on age t from birth to weaning in the present study. Differences in the shape of curves for frame and sex were tested, and if differences were significant, a final model by frame, sex, or frame by sex was defined.

To study the possible environmental effects on growth curve shape, multiplicative growth models also were fitted for each month of birth (January, February, and March).

Stage 2: Weaning to 20 mo of Age (Males) or 32 mo of Age (Females). Body weights were collected from 1985 to 1988 at quarterly intervals and from 1989 to 1993 at monthly intervals (Table 2). Multiplicative growth models were fitted for each frame by sex group with sire, progeny within sire, and season (January to February, March to April, May to June, July to August, September to October, November to December) effects included in the model. Within the model, a second-order polynomial was used as the growth curve representation because the existence of a point of inflection was expected within this stage. Differences in shape of curves for frame and sex were tested, and if differences were significant, a final model by frame, sex, or frame by sex was defined.

Stage 3: 32 mo of Age to Maturity (Females). Only females with data collected after 48 mo of age (1985 to 1989) were selected for estimation of the asymptotic curve. Body weights collected from these selected females from 18 mo of age on were used to estimate the asymptotic curve. However, the final curve from 32 mo of age to maturity was used. Data within 3 mo before and 3 mo after calving were deleted to prevent bias in the estimation of parameters.

Multiplicative growth models were fitted for each frame size with sire, progeny within sire, and season (March to April, May to June, July to August, September to October, November to December) effects included in the model. Within the model, a second-order polynomial was used as the growth curve representation. Differences in shape of curves for frame and sex were tested, and if differences were significant, a final model by frame, sex, or frame by sex was defined.

Using the estimates from the final multiplicative model, the original logarithmic data were corrected for effects due to sire, progeny within sire, and season; the method of Marquardt (1963) was used to fit the final asymptotic model of Brody (1945). To obtain the initial solution for the asymptotic fitting process, the method of Verhagen (1960) was used.

Life-Cycle Growth Curves. To define the birth to final age BW growth curves, a growth stage multiplicative model (Menchaca, 1992) by frame × sex was used. For stages 1 and 2, a multiplicative model was defined using data from animals represented in both stage 1 and 2, in order to have the entire curve represented by the same animals. Because of the existence of a 1-mo adaptation period after weaning, a transition stage was defined between stages 1 and 2. This transition stage was represented by the model $W = \exp(a + bt)$, where W represents body weight and t age in months. This expression represents the line that connects BW at the beginning of the transition stage (205 d), evaluated from the growth curve of the first stage, with BW at the end of the transition stage (235 days), evaluated from the growth curve of the second stage, all this in the logarithmic scale. The estimation process of the parameters a and b was through a system of equations that was defined using BW estimated from the growth curves at the beginning and ending points of the transition stage:

$$\log[BW(205)] = a + 205b, \text{ and } \log[BW(235)] = a + 235b.$$

In the case of females, the third stage also was included in the model to estimate the life-cycle growth curve. Data from fewer animals were used to estimate the curve for the third stage than for the first and second stages. Some assumptions were needed to join the second and third stages to obtain a continuous curve. The main assumption was that the effects of animals included in the second but not the third stage could adjust the curve only in a proportional manner because animal effects were considered multiplicative in the model. With this underlying assumption, a factor (F) was defined and used to adjust the third stage curve to join the second stage curve. The curves were joined at a common age (t*) where in both curves BW and instantaneous BW gain were the same. This was accomplished by solving the following system of equations:

$$\exp(\hat{a} + \hat{b}t^* + \hat{c}t^{*2}) = F \exp(\hat{A} + \hat{B}\exp(\hat{k}t^*)),$$

$$\frac{d}{dt}[\exp(\hat{a} + \hat{b}t^* + \hat{c}t^{*2})] = \frac{d}{dt}[F \exp(\hat{A} + \hat{B}\exp(\hat{k}t^*))],$$

where '^' represented least squares estimate, t* the common age, F was the factor used to adjust the third stage curve, and '$\frac{d}{dt}$' represented the derivative with respect to t (age).

Results and Discussion

Stage 1: Birth to Weaning. For the six frame by sex data sets, high levels of fit were obtained with $R^2 > .99$ for all cases. Scatter diagrams of residuals showed the adequacy of the fitted models (no violations of additivity or of homogeneity of variances of the models in the logarithmic scale).

Sex curves did not differ in shape, but frame curves did ($P < .01$). Because of this result, the following growth model was established for each frame size:

$$W_{ijkm} = A \exp(bt + ct^2)\; P_i\; S_j\; U_{ijk}\; E_{ijkm},$$

where A is a constant that occurs with every observation, b and c are growth curve parameters on age t (month), P is the sire effect, S is the sex effect, U is the progeny within P × S random effect, and E is the residual random error. Levels of fit were high, with $R^2 = .99$ for all the cases. Residuals showed the

Table 3. Parameter estimates and standard errors for growth curves from birth to weaning for Brahman calves of three frame sizes

	Small frame		Medium frame		Large frame	
Item	Constant	SE	Constant	SE	Constant	SE
Growth curve[a]						
a	3.39282	.00836	3.48342	.01228	3.59697	.00786
A	(29.7)[b]		(32.6)		(36.5)	
b	.463311	.005915	.467238	.007947	.452262	.005235
c	−.0264330	.0008006	−.0278591	.0011008	−.0264639	.0007340
Sex						
Male	.0447638	.0064664	.0295028	.0122803	.0367449	.0062432
	(1.04578)		(1.02994)		(1.03743)	
Female	−.0447638	.0064664	−.0295028	.0122803	−.0367449	.0062432
	(.95622)		(.97093)		(.96392)	

[a]Age t in months.
[b]( ) = values in the original scale, kg.

Table 4. Performance of Brahman calves at the point of inflection of the growth curve from birth to weaning for three frame sizes

	Frame		
Item	Small	Medium	Large
Age at inflection, mo (d)	4.42 (132)	4.22 (127)	4.20 (126)
Weight at inflection, kg	137.4	141.2	152.8
Gain at inflection, kg/d	1.053	1.097	1.172
Weight/age at inflection, kg/d	1.038	1.115	1.213
Gain/weight at inflection, %/d	.766	.777	.767

adequacy of the fitted models by their "normal" scatter diagram patterns (no violations of additivity or of homogeneity of variances of the models in the logarithmic scale). Male calves were heavier than female calves, 9.4% for small ($P < .001$), 6.1% for medium ($P < .01$), and 7.6% for large ($P < .001$) frames (Table 3). There were sire effects within small ($P < .001$), medium ($P < .01$), and large ($P < .01$) frames. Small frame attained its maximum instantaneous daily gain (point of inflection) 5 d later than medium frame and 6 d later than large frame (Table 4). This may be related to lower nutrient requirements for small frame calves. Frame curves were similar in shape for medium and large frame groups, although large frame animals were heavier ($P < .01$) than medium ones.

In general, points of inflection showed that maximum instantaneous daily gains were attained approximately 2.6 mo before weaning (Figure 1). The decrease in rate of growth after this time was possibly due to decreasing milk production of the dams and due to decreasing quality of pasture as the season progressed. This suggests that, in the 2.6 mo before weaning (approximately the last 40% of the preweaning period), there is a loss in daily gain potential that could be ameliorated by supplementation, if it were economically feasible. This could be particularly important in the case of females where preweaning growth rate can affect subsequent reproductive performance (Laster et al., 1976).

Body weight at inflection increased from small to large frame as expected (Table 4). Gain and weight/age at inflection followed the same pattern due to the relationship of these traits with BW. Relative gain (i.e., gain/weight) at inflection, however, was similar among frame sizes. This indicated that the observed difference among frame sizes in maximum instantaneous daily gain was related to differences in BW.

Growth curves by month of birth indicated that animals attained their maximum instantaneous daily gain between the middle of May and the middle of June, with points of inflection decreasing from birth months of January to March for all frames. This is illustrated for the case of large frame in Figure 2. For the birth month of March, the points of inflection for the different frames (Table 5) were comparable with previous results (our unpublished observations) in Romosinuano calves from Brahman recipients (experiment with seven animals and six observations per animal from birth to weaning) that indicated a point of inflection at 3.15 mo (94.5 d). The decrease of inflection point from birth months January to March could be associated with differences in the quantity and quality of pasture as the season progressed from spring to summer. Therefore, this loss in daily gain potential due to month of birth has potential implica-

Table 5. Points of inflection of the growth curve from birth to weaning for Brahman calves by frame size and month of birth

	Month of birth		
Item	January	February	March
Small frame			
Animals	145	74	34
n	357	174	80
Inflection, mo (d)	4.64 (139.2)	4.01 (120.2)	3.25 (97.4)
Medium frame			
Animals	58	24	16
n	153	62	40
Inflection, mo (d)	4.34 (130.3)	3.90 (117.1)	3.23 (99.7)
Large frame			
Animals	106	89	55
n	270	229	135
Inflection, mo (d)	4.43 (132.9)	3.42 (102.7)	2.97 (89.1)

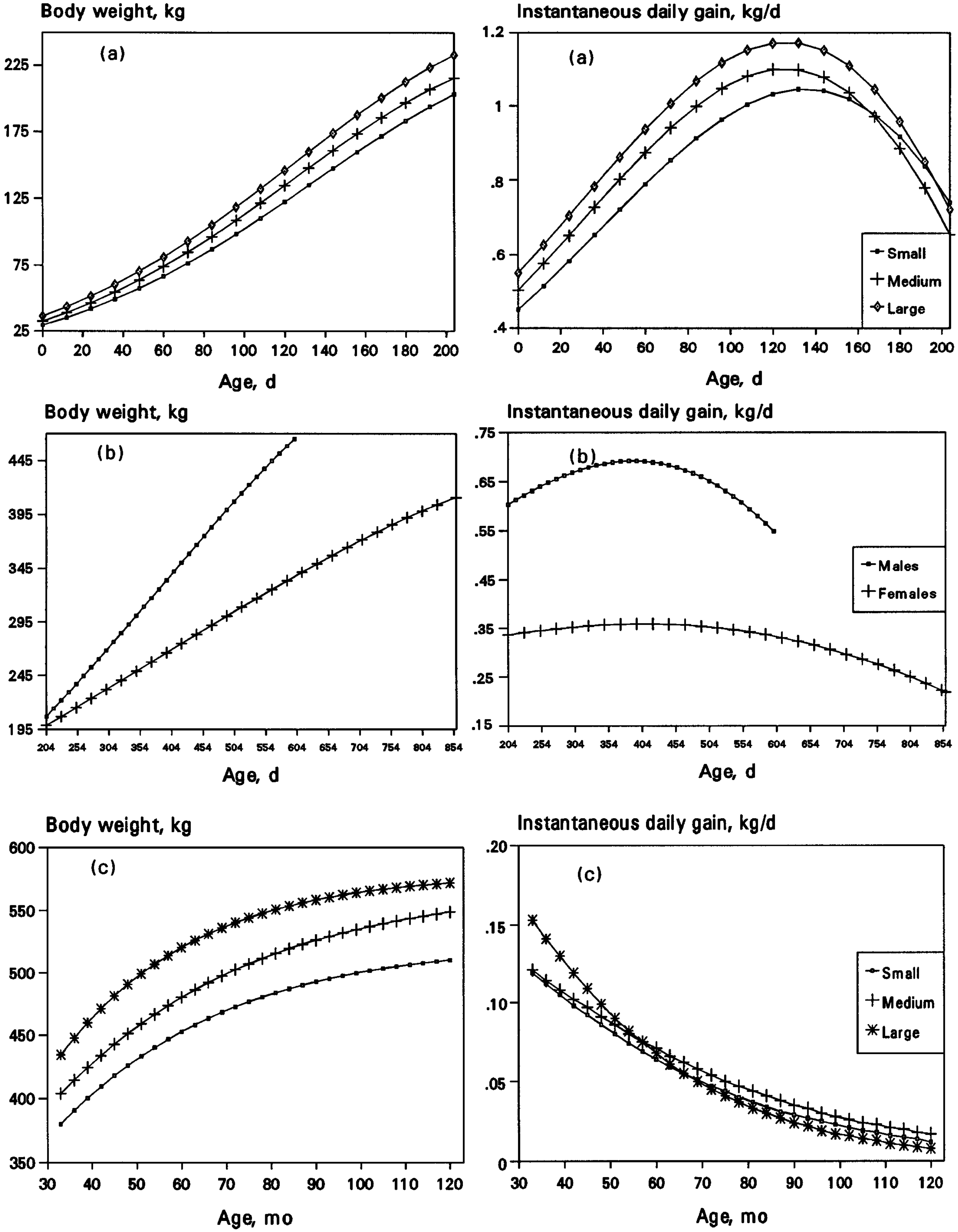

Figure 1. Body weight and instantaneous daily gain growth curves for Brahman cattle by stage of life: from birth to weaning for three frame sizes (a), from weaning to 20 mo of age for males and from weaning to 32 mo of age for females (b), and from 32 to 120 mo of age for cows of three frame sizes (c).

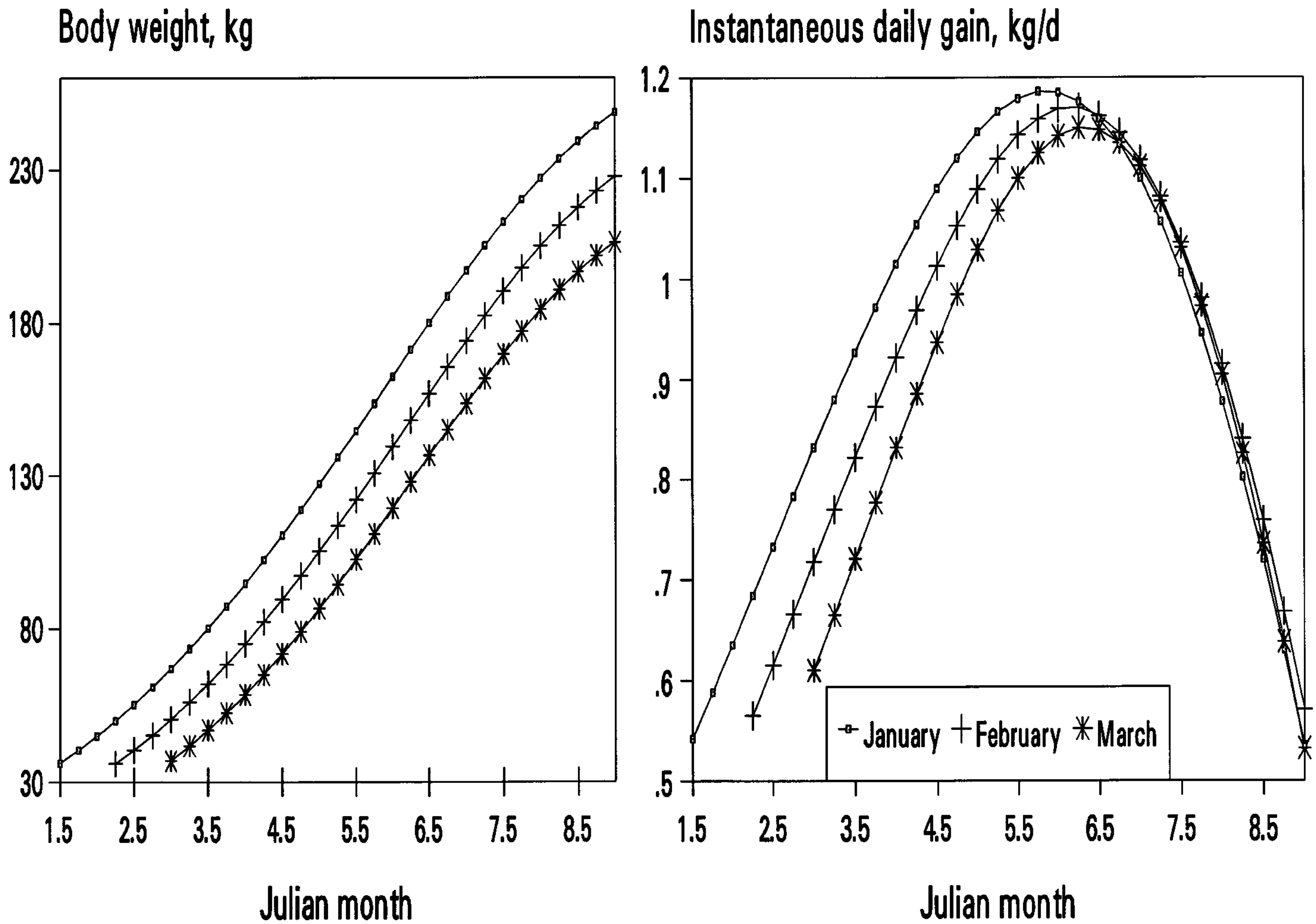

Figure 2. Body weight and instantaneous daily gain growth curves from birth to weaning by month of birth (January, February, or March) for large frame Brahman calves.

tions for selection of breeding season, pasture management, and supplementation strategies. From the birth month of January to the birth month of March, the differences in time to attain maximum daily gain were 6, 4, and 6 wk for small, medium, and large frames, respectively.

At weaning, large frame animals born in January were 20.9 kg heavier than those born in February and 42.3 kg heavier than those born in March. This difference had two sources of variation: age at weaning (fixed moment in the year for weaning all animals) and differences in age at inflection (i.e., days to attain maximum instantaneous daily gain). To study the pattern of the growth curve of the animals born in different months without the effect of age at weaning, curves were compared at a fixed age. In the case of large frame animals, BW at 6 mo of age (the mean age at weaning attained by animals born in March) were 213.0, 211.7, and 206.3 kg for birth months of January, February, and March, respectively. This indicated that a large proportion of the difference in weight among animals born in different months was due to a fixed date for weaning. Small frame attained its maximum instantaneous daily gain 6, 18, and 8 d later than the large frame animals born in January, February, and March, respectively. Similar to that obtained previously for the mean curve, this growth curve pattern could be related to lower nutrient requirements of the small frame animals. This observation has important implications for selection of frame size and nutritional management.

Stage 2: Weaning to 20 mo of Age (Males) or 32 mo of Age (Females). For the six frame by sex data sets, high levels of fit were obtained, with $R^2 > .95$ for all cases. Scatter diagrams of residuals showed the adequacy of the fitted models (no violations of additivity or of homogeneity of variances of the models in the logarithmic scale).

Frame curves did not differ in shape but sex curves did ($P < .001$). The following growth model for each sex was established:

$$W_{ijkmn} = A \exp(bt + ct^2)\ F_i\ P_{ij}\ U_{ijk}\ G_m\ E_{ijkmn},$$

where A is a constant that occurs with every observation, b and c are growth curve parameters on

Table 6. Parameter estimates and standard errors for multiplicative growth models of Brahman cattle from weaning to 20 mo of age (males) or weaning to 32 mo of age (females)

	Males		Females	
Item	Constant	SE	Constant	SE
Growth curve[a]				
a	4.64754	.01459	4.91078	.00884
A	(104.3)[b]		(135.7)	
b	.114139	.001669	.0615102	.0007694
c	−.00196922	.00005476	−.000796630	.000020690
Frame				
Small	−.068945	.010990	−.049441	.007927
	(.9334)		(.9518)	
Medium	.023076	.013828	−.019504	.010031
	(1.0233)		(.9807)	
Large	.045869	.011074	.068945	.007995
	(1.0469)		(1.0714)	
Season				
Jan–Feb	−.025495	.004313	−.017138	.002922
	(.9748)		(.9830)	
Mar–Apr	−.069458	.003245	−.048851	.002052
	(.9329)		(.9523)	
May–Jun	.012328	.003615	−.001663	.002137
	(1.0124)		(.9983)	
Jul–Aug	.017096	.002867	.021623	.002237
	(1.0172)		(1.0219)	
Sep–Oct	.058871	.003672	.026825	.002187
	(1.0606)		(1.0272)	
Nov–Dec	.006658	.003899	.019204	.002187
	(1.0067)		(1.0194)	

[a]Age t in months.
[b]( ) = values in the original scale, kg.

age t (month), F is the frame effect, P is the sire effect within frame, U is the progeny within sire within frame random effect, G is the seasonal effect (January to February, March to April, May to June, July to August, September to October, November to December), and E is the residual random error.

At the end of stage 2, the mean ages of bulls and heifers were 20.1 and 28.6 mo, respectively. There were high levels of fit, with $R^2 > .95$ for males and females. Residuals showed the adequacy of the fitted models by their normal scatter patterns (no violations of additivity or of homogeneity of variances). For both sexes, frame effects were different ($P < .001$). Sires within frames were different ($P < .001$) for both sexes, and seasonal effects were important ($P < .001$) in all cases. Large frame was 12.2% and 12.6% heavier than small frame for males and females, respectively (Table 6). Male BW growth curves had greater rates of growth than those of females (Figure 1). Point of inflection was attained first by males (16 d earlier than by females). At inflection (Table 7), males were 22.6% heavier than females and had a 92.8% greater instantaneous daily gain with a 57.1% greater relative gain (gain/weight); weight/age at inflection was 27.3% greater for males than for females. The difference between sexes in relative gain at inflection (i.e., gain/weight) may have been due to different rates of growth between sexes and different feeding and management systems.

Seasonal effects (Table 6) were negative during the first months of the year because of the negative effects of low winter temperature and relatively low rainfall on pasture growth (predominantly warm-season grasses), as well as the relatively low quality of preserved forage (hay) fed during this time of year. The difference between the best and worst seasonal effect was greater for males (14%) than females (8%) and was probably related to the different levels of supplemental feeding.

Table 7. Performance of Brahman bulls and heifers at the point of inflection of the growth curve from weaning to 20 mo of age (bulls) or weaning to 32 mo of age (heifers)

Item	Males	Females
Age at inflection, mo (d)	13.05 (391)	13.55 (407)
Weight at inflection, kg	330.8	269.9
Gain at inflection, kg/d	.692	.359
Weight/age at inflection, kg/d	.845	.664
Gain/weight at inflection, %/d	.209	.133

Table 8. Parameter estimates and standard errors for multiplicative effects of season affecting Brahman body weight growth curves from 32 months of age to maturity (females)

Season	Frame: Small		Frame: Medium		Frame: Large	
Mar–Apr	−.047064	± .005050	−.054112	± .009419	−.062045	± .004938
	(.9540)[a]		(.9473)		(.9398)	
May–Jun	.022826	± .005094	.018240	± .009685	.025914	± .004905
	(1.0231)		(1.0184)		(1.0263)	
Jul–Aug	−.026191	± .008645	−.016060	± .016790	−.007923	± .008803
	(.9741)		(.9841)		(.9921)	
Sep–Oct	.040688	± .004875	.032294	± .009278	.037806	± .004982
	(1.0415)		(1.0328)		(1.0385)	
Nov–Dec	.009741	± .006110	.019638	± .011376	.006248	± .005579
	(1.0098)		(1.0198)		(1.0063)	

[a]( ) = values in the original scale.

Stage 3: 32 mo of Age to Maturity (Females). Growth curves differed in shape among frames ($P < .05$). To study growth curves by frame, the following model was defined:

$$W_{ijkm} = A \exp(b \exp(ct)) P_i U_{ij} G_k E_{ijkm},$$

where A is a constant that occurs with every observation, b and c are growth curve parameters on age t (month), P is the sire effect, U is the progeny within sire random effect, G is the seasonal effect (March to April, May to June, July to August, September to October, November to December), and E is the residual random error.

There was a good level of fit for the three frames ($R^2 > .74$). Residuals showed the adequacy of the fitted models by their normal scatter diagram patterns (no violations of additivity or of homogeneity of variances). Sire effects were not significant within frame size, but season effects (Table 8) were important ($P < .05$). As in stage 2, seasonal effects were negative during the spring (March to April) because of pasture quantity and hay quality. In this stage (stage 3), there also were negative effects in July to August that were likely due to low forage quality, which is typical of late summer in Florida. In stage 2, the effects of low forage quality in late summer was probably masked by supplementation and the use of higher quality legume pasture. Brody's curve (Table 9) showed good levels of fit, with partial coefficients of determination over 69%. As expected, large frame cows had higher ($P < .05$) asymptotic BW (A) than small frame cows, and medium frame cows had intermediate asymptotic BW (Figure 1). Note that asymptotic BW were extrapolated from data that had 90 mo of age as a mean for the ending age point. Although large frame cows had greater rates of growth than medium and small frame cows before 4 yr of age, this pattern of the growth curve was reversed from 57 mo of age (75 g/d) for medium frame and from 66 mo of age (55 g/d) for small frame (Figure 1). At 90 mo (mean ending age), the instantaneous daily gains were 24, 29, and 35 g/d for large, small, and medium frame cows, respectively.

Life-Cycle Growth Curves. Parameters for the life-cycle BW growth curves are presented in Table 10 (males) and in Table 11 (females). Birth to final age BW and instantaneous gain curves (Figure 3) showed the general pattern of growth expected for beef cattle. Maximum rate of growth in the preweaning stage was higher than in the postweaning stage, with a greater difference in the case of females, mainly due to levels of feeding. Thus the growth performance observed postweaning was probably below the growth potential of the animals. If the instantaneous gain is at a lower level than the gain potential of the animal (theoretically the maximum instantaneous gain is attained at the onset of puberty, Brody [1945]), then there is a potential for growth that could be exploited if it were economically feasible. This would be of particular importance in heifer development systems in which adequate pre- and postweaning rates of gain are necessary for heifers to reach puberty to calve first at 2 yr of age.

The aberrant pattern of the growth curve in the transition period after weaning was expected due to the effects of weaning. In this period, animals displayed low or negative daily gains. Although this is of a relatively short duration, approximately 1 mo, it is identified as a period of special concern with regard to the potential for achieving improved overall production efficiency.

In summary, growth curves for small, medium, and large frame Brahman cattle were characterized by stage of life cycle. Growth curves for different frame sizes and different sexes had different patterns, depending on the stage of life cycle. These results could be utilized to identify areas in which production efficiency could be improved. The direct effect of season on growth curves could have important impli-

Table 9. Parameter estimates, approximate standard errors, and partial coefficients of determination of Brody's growth curve[a] for Brahman females of three frame sizes

	Small frame		Medium frame		Large frame	
Item	Constant	SE	Constant	SE	Constant	SE
A	6.26062 (523.5)[b]	.01717	6.34297 (568.5)	.04291	6.36082 (578.7)	.01117
B	−.841526	.020318	−.811676	.030982	−.965287	.031469
k	−.0293053	.0021959	−.0262095	.0043630	−.0368143	.0021264
R^2	.755		.696		.754	

[a]Age t in months.
[b]( ) = values in the original scale, kg.

Table 10. Parameter estimates and standard errors for the life-cycle body weight growth curve (birth to 20 mo) of Brahman males of three frame sizes

	Small		Medium		Large	
Item	Constant	SE	Constant	SE	Constant	SE
Birth to 6.8333 mo, $W = \exp(a + bt + ct^2)$[a]						
a	3.39434	.01478	3.51212	.02214	3.64130	.01492
b	.468979	.009495	.459097	.012964	.449049	.007504
c	−.0270225	.0012841	−.0263289	.0017496	−.0262696	.0010556
6.8333 mo to 7.8333 mo, $W = \exp(a + bt)$[a]						
a	5.20296	—	5.17059	—	5.54446	—
b	.01965	—	.03648	—	−.00897	—
7.8333 mo to 20 mo, $W = \exp(a + bt + ct^2)$[a]						
a	4.60202	.03893	4.72737	.05855	4.69564	.03723
b	.111149	.005967	.106740	.009108	.114565	.005777
c	−.00188729	.00021890	−.00174624	.00034243	−.00193731	.00021672

[a]Age t in months.

Table 11. Parameter estimates and standard errors for the life-cycle body weight growth curve (birth to 90 mo) of Brahman females of three frame sizes

	Small		Medium		Large	
Item	Constant	SE	Constant	SE	Constant	SE
Birth to 6.8333 mo, $W = \exp(a + bt + ct^2)$[a]						
a	3.32331	.01368	3.45078	.02062	3.55800	.01510
b	.473662	.009209	.477968	.013897	.461571	.007573
c	−.0273991	.0012319	−.0298006	.0019293	−.0276090	.0010671
6.8333 mo to 7.8333 mo, $W = \exp(a + bt)$[a]						
a	5.22404		5.36695		5.52457	
b	.00827945		−.00608670		−.0148816	
7.8333 mo to 33 mo, $W = \exp(a + bt + ct^2)$[a]						
a	4.85933	.01161	4.90078	.02189	4.97650	.01195
b	.0609564	.0006962	.0592648	.0013483	.0612182	.0007189
c	−.00078108	.00001330	−.00074535	.00002606	−.00078295	.00001379
33 mo to 90 mo, $W = \exp(A + B\exp(kt))$[a]						
A	6.34024	.01717	6.38711	.04291	6.43094	.01117
B	−.841526	.020318	−.811676	.030982	−.965287	.031469
k	−.0293053	.0021959	−.0262095	.0043630	−.0368143	.0021264

[a]Age t in months.

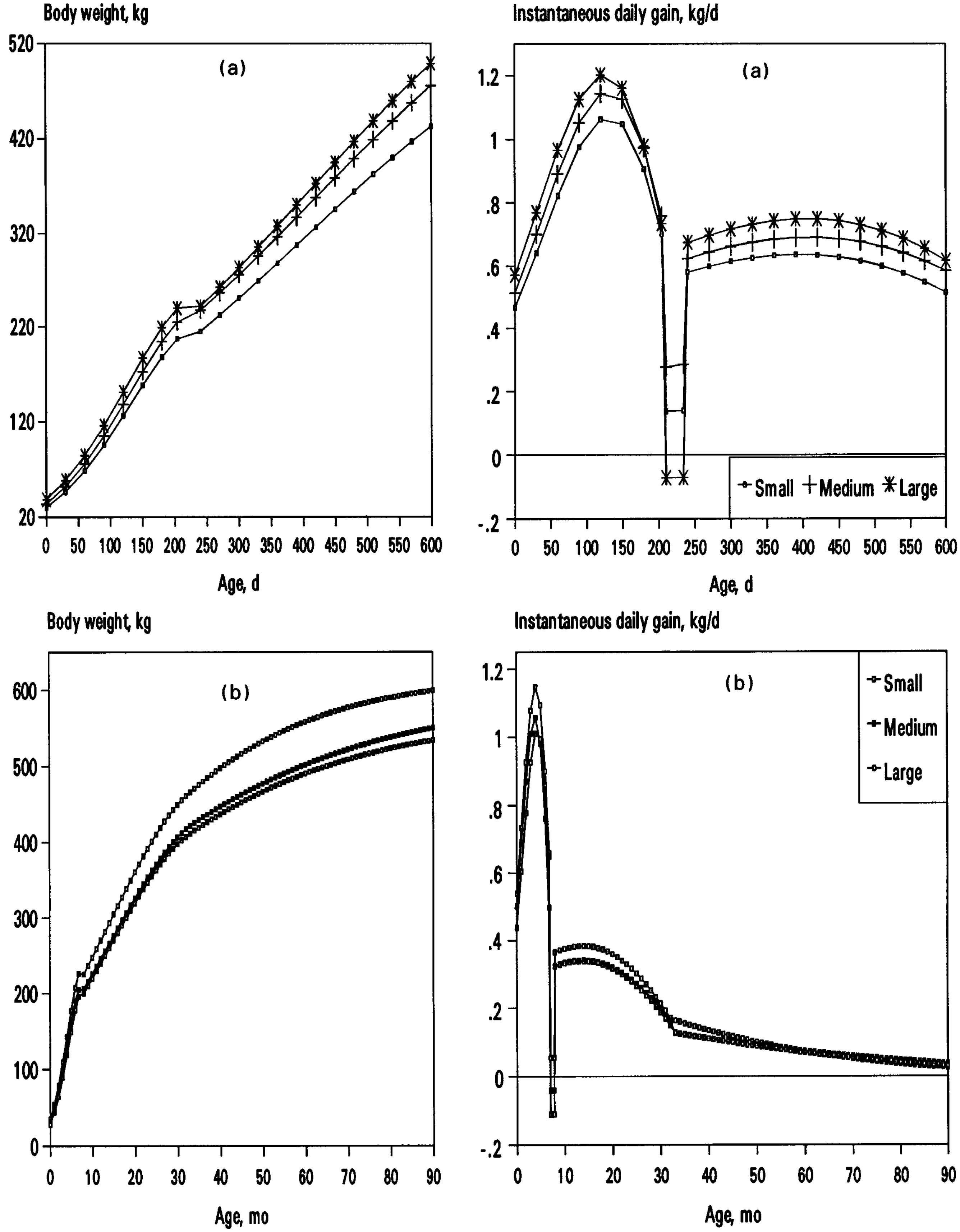

Figure 3. Body weight and instantaneous daily gain growth curves for the complete life-cycle of Brahman cattle: from birth to 20 mo of age for males of three frame sizes (a) and from birth to 90 mo of age for females of three frame sizes (b).

cations for production management decisions. The instantaneous daily gain curve of calves before weaning in this subtropical grazing system suggested the potential for improving growth during the last 2.6 mo of the period with suitable supplementation, particularly in the case of females. Also during the preweaning period, the month of birth was shown to influence potential daily gain, demonstrating the importance of timing of the breeding (calving) season. The transition period of approximately 1 mo after weaning was identified as a strategic point at which growth performance is compromised and therefore potentially subject to improvement. Also, these data suggest that potential growth rate in females could be better exploited during the period from weaning to the onset of puberty, decreasing age of puberty and thereby increasing reproductive efficiency if it were economically feasible.

Implications

Analysis of growth curves can be used to identify areas in the entire life-cycle production system that could be targeted for strategic changes aimed at improving production efficiency. In this study of different frame size Brahman cattle in a subtropical environment, areas identified in which biological efficiency might be improved were pre- and postweaning nutritional management, breeding (calving) season, and management at weaning.

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